MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A
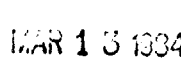
AD A138945

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 5268		5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION Naval Research Laboratory	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION			
6c. ADDRESS (City, State and ZIP Code) Washington, DC 20375		7b. ADDRESS (City, State and ZIP Code)			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Defense Nuclear Agency	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (City, State and ZIP Code) Washington, DC 20305		10. SOURCE OF FUNDING NOS.			
		PROGRAM ELEMENT NO. 62715H	PROJECT NO.	TASK NO.	WORK UNIT NO. 47-1606-0-4
11. TITLE (Include Security Classification) (See page ii)					

12. PERSONAL AUTHOR(S) B.H. Ripin, J. Grun, S. Kacenjar, E.A. McLean, and J.A. Stamper				
13a. TYPE OF REPORT Interim	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Yr., Mo., Day) February 22, 1984		15. PAGE COUNT 39

16. SUPPLEMENTARY NOTATION This research was sponsored by the Defense Nuclear Agency under Subtask I25BMXIO, work unit 00024 and work unit title "Early Time Plasma."

17.	COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	HANE Laser-plasma Shocks
			Instabilities Magnetized ion-ion

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A brief overview of the NRL laser-target experiment which simulates the interactions involved in a HANE is presented. A burst of fast laser-produced-debris-ions stream into a low-density magnetized ambient plasma/gas. The interactions between these two plasma components are investigated under a variety of conditions.

At ambient pressures below 150 mTorr we observed a magnetic bubble formation during the debris expansion; we found that the field is swept out of the volume traversed by the debris plasma and is compressed ahead of the debris front. Evidence is found for magnetic-field dependent interactions between the debris ions and ambient plasma.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL B. H. Ripin	22b. TELEPHONE NUMBER (Include Area Code) (202) 767-2730	22c. OFFICE SYMBOL Code 4732

DD FORM 1473, 83 APR   EDITION OF 1 JAN 73 IS OBSOLETE.

i

MAR 1 3 1984

A

11. TITLE

INTRODUCTION TO THE LASER-HANE EXPERIMENT AND SUMMARY OF LOW-PRESSURE
INTERACTION RESULTS

CONTENTS

iii

INTRODUCTION TO THE LASER-HANE EXPERIMENT AND SUMMARY OF LOW-PRESSURE INTERACTION RESULTS

I.   Introduction

DNA's Division of Atmospheric Effects (RAAE), initiated a laser-target HANE-simulation experiment at the Naval Research Laboratory in early 1982. The objective of this experiment is to study the mechanisms involved in a HANE event, especially those which affect the early-time evolution of the plasma structure.[1]   The experiments have two goals.   The first objective is to emulate a nuclear event as closely as possible.   Laboratory parameters which cannot directly duplicate those of a real or hypothetical HANE, such as masses and distances, have to be scaled using an appropriate scaling argument.   The second goal is to study relevant physical effects or mechanisms, even if the experimental parameters are quite far from that of a direct simulation.   In either case coupling to the theoretical activity in the HANE-community is desirable to achieve a better understanding of the consequences of a HANE-like event and its relationship to the laboratory findings.

The experiment to date has focused on three regimes of interest.   These are:

o   *Collisionless Coupling Regime (low ambient pressure).*

o   *Collision Dominated Regime (high ambient pressure).*

o   *Disassembly Regime (high debris density, high debris acceleration).*

The collisionless coupling (or low-pressure) regime is used to address the mechanisms involved in the debris-air coupling at high-altitudes (such as in Starfish), where collisionless or Longmire coupling is operative; a review of our experiments in this regime forms the major portion of this and the next paper.[2]

1

When ambient gas pressure is above a few-tenths of torr (high-pressure), the experiment exhibits collisional characteristics that correspond to HANE conditions in the 100 to 200 km altitude range (such as Checkmate). Our first experiments in this regime is the subject of several other papers in this proceedings.[3,4,5]

Finally, the disassembly regime is concerned with the nonuniformities that may result during the detonation stage when the weapon material is highly accelerated outward by the released energy; a primary question is whether these nonuniformities grow due to Rayleigh-Taylor instability[6] and evolve into later-time structure.[7] Experiments addressing this subject are the subject of another paper in this proceedings.[8]

II. Experiment and Diagnostics

I will now outline the configuration of the present experiment and the parameter regimes that are accessible. Enhancements to the laser and target facility presently being made will also be briefly described.

The experiment involves focusing beams from the NRL-Pharos II Nd-laser (1.05 µm wavelength) onto a small (< 1 mm dia, few-microns thick foil) solid target in the center of the target chamber. Target material is ablated by the laser irradiation and streams radically outward with kinetic energy densities comparable to those resulting from a weapon detonation. A low-density background gas in the chamber is promptly ionized near the target by radiation from the laser-target interaction (photoionization), and at later times by the expanding debris (UV photoionization from the debris shell or by particle impact). This creates an ambient plasma, through which the high-velocity nuclear-like debris streams, emulating the ionospheric conditions surrounding a detonation; an external magnetic field can be applied over the whole interaction

2

region, using permanent magnets or coils, to mock-up the ionospheric magnetic field. As we will see, with appropriate scaling the spatial dimensions of the relevant interaction region is of the order of centimeters, the time-scales involved are fractions of a microsecond, the magnetic fields are close to kilogauss and the required ambient gas pressure is below ten Torr (1 Torr = 1 mm of Hg = 3.24×10^{16} molec/cc). The laser-pulse energy requirement to simulate a detonation is also reasonable, being 10 to 1000 Joules. Figure 1 shows the experimental arrangement schematically. Some of the present and (to be) upgraded facility specifications are tabulated in Table I. The facility upgrade, which includes extensive modifications to both the laser and the target areas, is expected to be completed in late FY-84 or early FY-85.

Table I. Facility Specifications

	LASER			CHAMBER/GAS		MAGNETIC FIELD	
	Energy[a] (J)	λ (μm)	#Beams	Diameter (cm)	P[b] (Torr)	B(kgauss)	Coil Diameter (cm)
Present	400	1.05	2[c]	60	$> 10^{-5}$	0.8[d] 0-1[e]	5 10
Upgrade	1500	1.05[f] 0.53[f]	3[g] 2-3	130	$> 10^{-6}$	0-10[e]	26

(a) In a 3-4 nsec pulse; a 300 psec pulse duration is also available at reduced total energy
(b) Any gaseous species
(c) One-sided illumination
(d) Permanent magnet
(e) Helmholtz and dipole coil configurations
(f) Narrow or broad bandwidth laser pulse
(g) One or two-sided illumination

Many diagnostics are available to measure the evolution of the debris-plasma interaction; and others are currently being developed.[9] Diagnostics include devices to measure: the incident and reflected laser energy and time-history, the angular distributions of the resulting debris energy, velocity,

3

mass, and momentum. Magnetic probes measure the magnetic field distortions during the debris/background plasma interactions and self-generated magnetic field components as a function of position and time. Electric probes give similar information about the electric field and plasma properties in low-density plasma. Optical diagnostics such as shadowgraphy and interferometry yield quantitative pictures of the plasma density structure at moderate-to-high densities (> 10^{17} electrons per cm^3) optical imaging with still-photography, time-resolved framing photography, or streak photography also give qualitative and quantitative information on density structure. Spectroscopy, from the infrared to XUV, is used to give spatially and temporally resolved information about the velocity, temperature, ionization state, density, emissivity, opacity, etc. of the debris material, the photoionized background plasma, and the interaction between them. Ion analyzers (under development)[10] will allow measurements of the debris and reflected ambient ion velocity and species distributions along and across the magnetic field. Knowledge of the ion properties is valuable in resolving many of the current questions about early-time HANE instabilities. X-ray and XUV diagnostics allow diagnosis of plasma properties above about 20 eV; pinhole or imaging photography gives 2-D spatially-resolved images while electronic x-ray and UV detectors give quantitative information about the initial debris plasma temperature, the UV emission from the expanding debris-ambient plasma front, etc. Still other novel techniques are used for specific information. Tracer-dot techniques, in which small dots of a high-Z material are implanted in the target surface, have proved valuable in providing debris flow visualizations and spatially resolved quantitative spectroscopy.[11] Resonant and nonresonant laser scattering in the disturbed plasma has been proposed to measure the density power spectrum.[12] The experiment can also provide a short-pulse x-ray flash for quantitative x-ray

4

radiography of the highly-accelerated ($> 10^{15}$ cm/sec^2), high-density (> 0.1 solid) targets in the accelerating target regime.[13]   Highly accelerated targets, which can be purposefully structured, are being used to study the hydrodynamic stability of material during device disassembly and the sensitivity of plasma structure evolution to nonuniformities in the target.[13-16]

III. Scaling of Laser-Experiment to HANE:

Scaling of HANE-parameters down to laboratory conditions is predicated on several alternate sets of assumptions, depending upon the physics of interest. No set of assumptions will simultaneously reproduce all aspects of a HANE event; one should, therefore, consciously choose which physical conditions are to be retained on the basis of their importance to the experiment.   Longmire formalized one scaling scheme by fixing the debris velocity in the laboratory experiment to be equal to that of a real HANE and by preserving binary collisions;[17] this scaling preserves binary collision effects but not magnetic field and plasma instability effects.   It is a reasonable approach when details of collisions are crucial.   Also, it gives a feeling for how parameters scale from a HANE down to the laboratory.   Table II shows Longmire collisional scaling relations as a function of the yield ratio $Y \equiv E_\ell/T_w$ between the HANE-weapon and laboratory debris kinetic energies.   As mentioned before, most of these parameters are achievable in the experiment.   But, if the focus of a particular investigation is the role of streaming instabilities for "collisionless" debris-air momentum transfer,[18] other scaling relations are more appropriate. Scalings which emphasize instability coupling have been discussed by ourselves[12] and, more thoroughly, by Tsai, DeRaad and Lelevier (RDA),[19] Smith and Huba (NRL),[20] Stellingwerf, Longmire and Alme (MRC),[21] and Sperling (JAYCOR).[22]   These scalings generally relax the debris velocity and

5

material constraints but require stronger magnetic fields than strict B^2/nkT scaling. The parameters of the target facility upgrade were, in fact, chosen to allow clean studies of this type. Undoubtedly, other phenomena of interest, such as MHD-EMP, highly-accelerated dense material, etc., require still other scaling emphasis.

The targets can be irradiated in three modes: the exploding-pusher mode; the ablation mode; and the accelerating target mode. The exploding pusher mode[23] occurs at high laser irradiance and yields very high-velocity ion debris (but with a broad nonreproducible distribution). The ablation mode[24,25] occurs at lower laser irradiance ($I < 10^{14}$ W/cm^2) and yields a very reproducible narrow ($\Delta v/v \simeq \pm 0.1$) ion velocity distribution with mean velocity tunable between 10^7 and 8×10^7 cm/sec. This mode of operation is particularly suitable for detailed HANE investigations due to its simplicity, reproducibility, and cold ion distribution; this is the mode of preference for most studies. The third mode, the accelerating target mode,[14,24,25] uses the ablating debris to accelerate a thin target to high-speed (up to 2×10^7 cm/sec) while remaining near solid-density (> 0.1 solid density) and cold (< 10 eV). Each of these modes can be exploited for specific HANE studies.

The laser-plasma interaction can deposit energy densities comparable to those of a real weapon and set up conditions close to (but not identical to) actual HANE-events. The time and spatial scales are experimentally achievable and well-diagnosed experiments can be done in a repeatable and repetitive manner at modest cost (comparatively speaking). Therefore, with your help many issues crucial to HANE phenomenology and structure evolution will soon be tested.

A brief description of our exploratory experiments in the low-pressure or collisionless regime follows. We search for signs of a collisionless mechanism such as plasma instability that could couple the debris momentum to the ambient

6

Table II. Collisional (Longmire[2]) scaling of selected
HANE parameters with the relative energy ratio Y.

Parameter	Scaling	Representative values for $Y=10^{-12}$
Velocity	$v =$ constant	10^8 cm/sec
Mass (debris)	$m_d \propto Y$	0.1-1 µgm
Distances	$R \propto Y^{1/2}$	~ 1 cm
Time	$t \propto Y^{1/2}$	~ 100 nsec
Background density gas	$p \propto Y^{-1/2}$	$10^{13}-10^{18}$ atoms/cc
*Magnetic field	$B \propto Y^{-1/4}$(a); $Y^{-1/2}$(b)	~ 1 kG (a); ~ 1 MG (b)
*MII instability	$\gamma\tau \propto Y^{1/4}$(a); const (b)	~ 1 (a); ~ 10^3 (b)

*The magnetic field does not scale uniquely. The (a) scaling preserve. .h·
magnetic field/plasma energy density ratio (B^2/nkT) which also preserve the
Alfven velocity constant; in this scaling the number of instability growth ..:s
is compromised. An alternate assumption (b) is to keep Larmor radii cons :nt
with other distance scales; this requires unrealistically high magnetic fi.

IV. Low-Pressure Ambient-Plasma Regime

In our first experiments in the low-pressure (< 150 mTorr) regime, we
search for signs of beam-plasma instabilities. These instabilities are thought
to effect debris-air coupling in high-altitude events, such as in Starfish (400
km), in which collisions alone are insufficient to transfer momentum from the
device debris to the ionosphere. The experimental configuration and the
ambient and debris ion velocity distributions are sketched in Fig. 2. Of the
five streaming instabilities thought to be relevant to HANE (Lampe et al.)[18]
we focus our attention on the magnetized ion-ion instability. The magnetized
ion-ion instability is an efficient momentum transfer mechanism with an
effective collision frequency of about one-tenth the lower hybrid frequency.

We are in a regime in which the debris ions are unmagnetized (cyclotron
radius >> equal mass radius), the ambient plasma is magnetized (electron and ion
cyclotron radii < the equal mass radius) and, most importantly, the debris

7

magnetic Mach number is high ($V_D > V_{Alfven}$). The latter constraint is deemed important to preserve the hydrodynamics of a HANE event.

The uncoupled debris ion distribution has high-velocity (up to 8×10^7 cm/sec) and a narrow spread ($\pm 10\%$) as seen in the typical time-of-flight detector signal of Fig. 3. The first blip is the t=0 marker (due to the x-ray flash from the laser-target interaction; this occurs on this plot at about 0.4). The mean velocity of the ions is 6×10^7 cm/sec in this case. The debris-ion distributions are well-behaved and reproducible in the absence of an interaction. Moreover, they can be tuned up or down in velocity by changing the laser irradiance.[25] The relative velocity between debris and ambient ion distributions exceeds the thermal spreads of the beams, thus satisfying the criteria for streaming instabilit\`.

When ambient gas is present, the debris distributions are altered. For ambient pressures of 80 millitorr and up, the debris ion distributions reaching the time-of-flight detector (about 22 cm away from the target) are attenuated and slightly broadened, as in Fig. 4. These changes to the debris velocity distributions are thought to be due to collisional proce ses, or at least magnetic field independent mechanisms, since they do not seem sensitive to the presence or absence ofa magnetic field (at least not sensitive to fields below one-kilogauss).

To test the collisional properties of the debris ions in traversing tens-of-centimeters of ambient plasma and gas before detection, we use the setup shown in Fig. 5. Three time-of-flight charge collector detectors are placed at 10 cm, 25 cm, and 55 cm distances from the target to detect ion distribution changes occurring between them.

One question is whether we can rely upon the preservation of the shape of the ion distribution in passing through the ambient media; if so we can detect

the effects of an interaction occurring within a few centimeters of the target much further away. The answer is seen in Fig. 6; at least through a mass-pathlength of 5×10^{16} molecules/cc * cm (i.e., 150 mTorr N_2 with $\ell = 10$ cm) both the peak velocity and velocity spreads are not strongly affected. Therefore, they can be used as good indicators of interactions close to the target.

Another related question is whether significant debris ion charge is being lost due to charge exchange processes between the target and detector. Figure 7 shows that the answer is affirmative for low-velocity carbon debris (< 350 km/sec) for mass-pathlengths above about 10^{16} molecules/cm^2, and for higher velocity Al at somewhat higher pressures. Thus, the attenuation of debris ions exhibited in Fig. 4 could be due to charge exchange or ion removal type processes.

Nonetheless some energy, albeit a small amount, is transferred from the debris to an expanding shell in the 100 mTorr regime; this is seen in the framing camera pictures of visible light emission, Fig. 8. A fuzzy shell expands with a speed of about 250 km/sec into a 100 mTorr N_2 background gas in which an 800 G external field was applied. Measurements of the magnetic field dynamics show that the ambient field is largely swept out of the region traversed by the debris and is compressed ahead of the debris front, as illustrated in Fig. 9. An extensive description of the magnetic field behavior is to be found in a paper by Kacenjar et al.[2] elsewhere in this proceedings.

V.   Collisionless Instability Regime

For what experimental parameters is the magnetized ion-ion instability most likely to be observed? To answer this question we examine the instability criteria outlined in Lampe et al.[18]   To satisfy the two most stringent

9

instability criteria, that of avoiding electromagnetic stabilization $(V_D/V_A \equiv M_A \lesssim 2.5)$ and fitting at least one parallel wavelength in the system size $(\lambda_{11} < 2\pi R_m)$, we should go in the direction of:

o Increasing the magnetic field

o Decreasing the ambient density

o Decreasing the drift velocity

o Decreasing the atomic number of the ions.

Smith and Huba quantitatively outlined expected regions of instability in laser energy-ambient pressure space, as shown in Fig. 10. For example, Figure 11 shows that carbon debris interstreaming through an 800 G magnetized ambient hydrogen plasma at a velocity of 400 km/sec should be MII unstable close to the experimentally accessible circled region. The outlined regions of instability assume full ionization of the hydrogen and therefore would move to the right in Fig. 10 if the gas is partially ionized (as indeed it is).

To detect the presence of instability, an array of four charge time-of-flight detectors is deployed perpendicular to the magnetic field direction but at various angles from the target normal, as sketched in Fig. 12.

A clear difference between the debris ion distributions with and without the magnetic field in place is seen in Fig. 13. Without a field present, as in the ion distributions on the left side of Fig. 13, the debris distributions are well-behaved and similar to those generated in a vacuum. In contrast, the distributions in the presence of the magnetic field (on the right) are broadened and have lower velocity (later-time) peaks which are like signatures of expected beam-plasma instability. The pressure is low and collisions play little or no role.

We used hydrogen gas to have a low the ambient-plasma atomic number in order to be more susceptible to instability, as indicated previously. To test the conjecture that lower atomic number is more unstable we compared debris ion distributions resulting from use of nitrogen (A=28) and hydrogen (A=1), as shown in Fig. 14. The magnetic field dependent interaction that occurring in hydrogen is not evident in nitrogen. This lends support to the notion that MII may be occurring in the carbon-hydrogen combination but not in carbon-nitrogen under our conditions.

Finally, sometimes ion signals are observed with components having higher velocities than in the original debris distributions. This occurs (for example in the circled regions of Fig. 15) at low incident laser energy in cases which exhibit the other signs of magnetic field dependent interaction. We have very few cases of this sort, and therefore the results are considered tentative. But, these "fast ions" may be the result of a reflection or acceleration process near the coupling region.

VI. Summary

The laser-target HANE-simulation experiment can examine physics questions relevant to HANE early-time phenomena in three regimes: the collisionless (low-pressure) regime, the collisional (high-pressure) regime, and the disassembly (dense high-acceleration) regime.

In the collisionless regime, the results of the first series of experiments show magnetic field dependent interactions between the debris ions and ambient plasma. In many ways these observations are similar to those expected from the magnetized ion-ion instability. However, an extensive study of collisionless plasma instability coupling awaits the upgraded laser and target facility.

11

VII. Acknowledgments

SHADOWGRAPHY
(2ω)

INTERFEROGRAPHY
(3ω)

BACKGROUND GAS
0-10 Torr

LANGMUIR PROBE
MAGNET PROBE

MAGNET

INCIDENT
LASER BEAM

X-RAY PINHOLE
CAMERA

MINI CALORIMETERS

OPTICAL PROBE BEAM

ION TIME-OF-FLIGHT
DETECTORS

FRAMING CAMERA
STILL CAMERA
SPECTROGRAPH
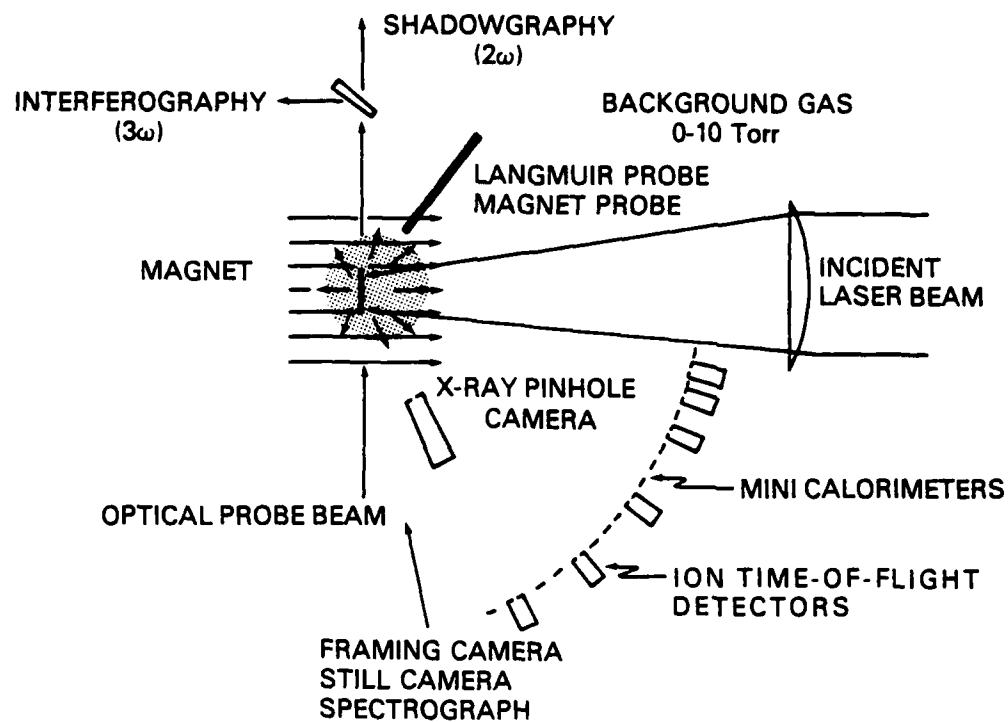
Figure 1   Experimental arrangement.

ionized gas

ambient   ablation

B
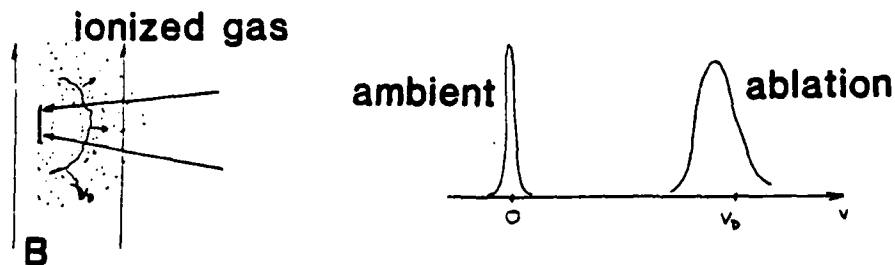
Figure 2   Schematic of the debris shell moving outward from the laser focal region through the magnetized photoionized ambient gas (left). The ambient (stationary) plasma and drifting target debris (ablation) plasma distributions form a classic interstreaming instability configuration (right).

13

ION TIME OF FLIGHT IN VACUUM

$I = 4.6 \times 10^{13}$ W/CM^2

CARBON TARGET

$B = 0$

SHOT11715-G003332P7

$V = 6 \times 10^7$ CM/SEC

$\dfrac{\Delta V}{V} = 0.22$

$E_C = 23.3$ KEV

ION CURRENT

TIME (μsec)
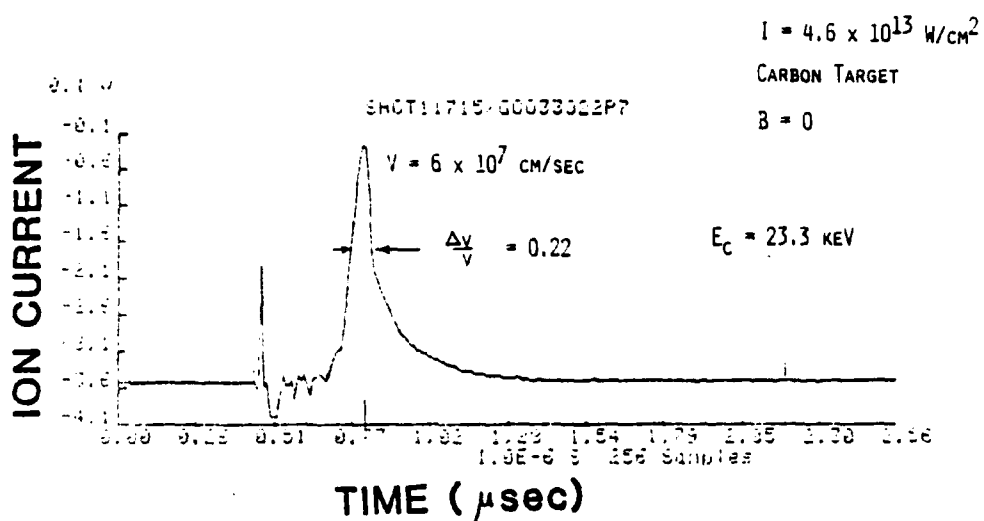
Figure 3   Debris ion time-of-flight detector signal.   Note the high-velocity, narrow-velocity spread debris peak.   These ions contain over 80% of the absorbed laser energy.

14

B-FIELD DEPENDENCE OF DEBRIS CHARGE TRACES
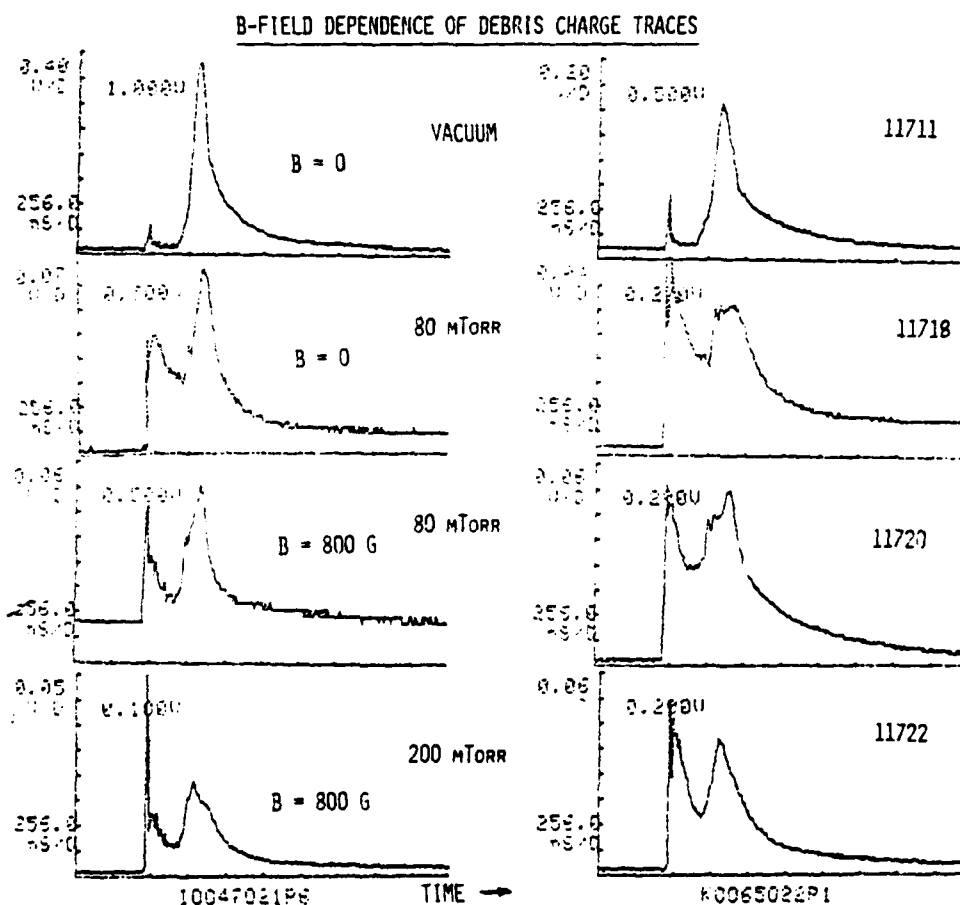
Figure 4   Debris ion time-of-flight data for moderate pressures (vacuum, 180 and 200 mTorr nitrogen), with and without a magnetic field.   Traces on the left were obtained with detectors oriented at 47° to the laser beam axis and those at the right at 65°.   Detectors were about 22 cm from the target and in a plane perpendicular to the magnetic field direction.

15

TARGET

LASER

TIME-OF-FLIGHT

10cm

15cm

30cm
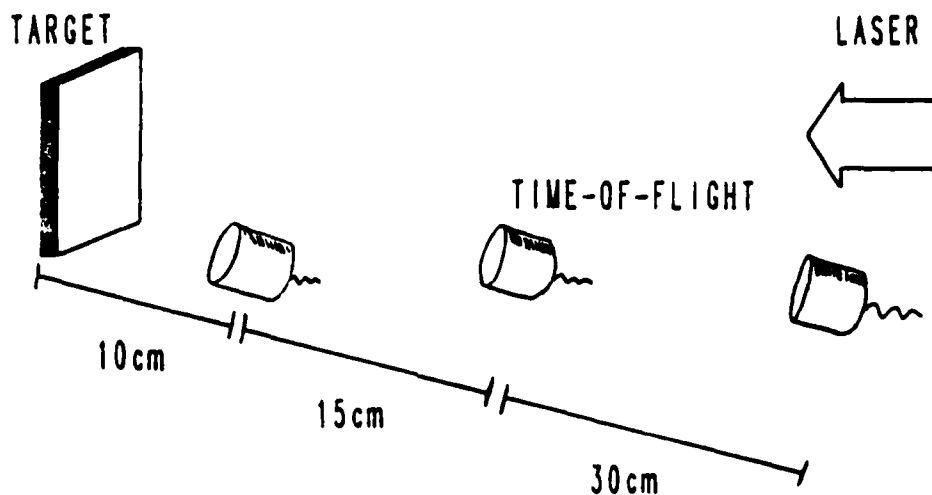
Figure 5   Setup to test the collisional properties of debris ions.

CURRENT vs AREAL DENSITY

VELOCITY (cm/sec*10^7)

∇ C --> VACUUM

○ C --> H$_2$

□ C --> N$_2$

1/2

1/10

TIME

MOLECULES/cm^2 x 10^{16}
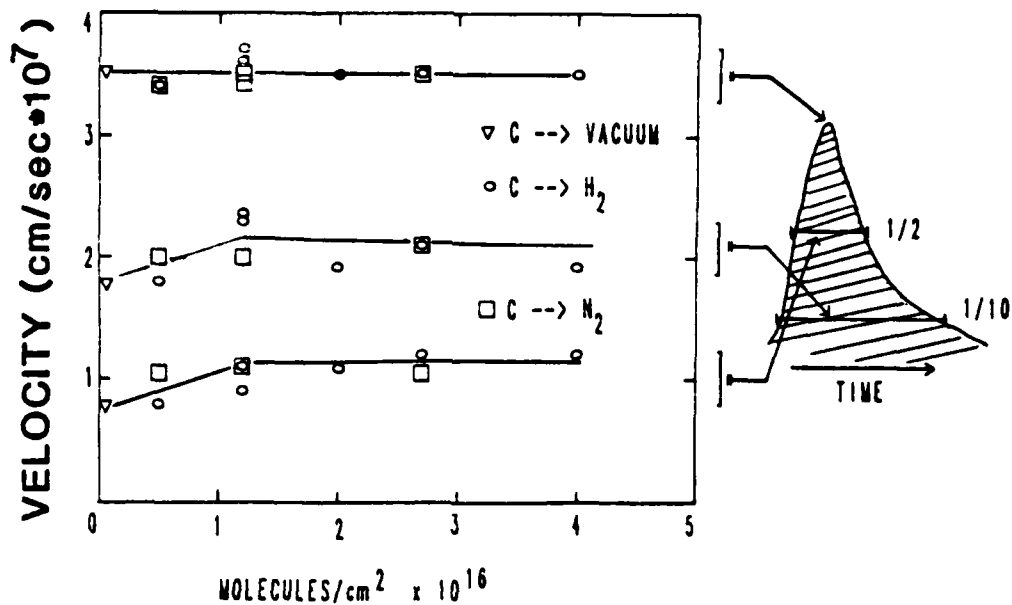
Figure 6   Peak-velocity and velocity spread (FWHM and ± 10% points) versus
mass path length of debris ions. No significant change in these ion
trace characteristics are seen below 5 x 10^{16} molecules/cm^2.

16

CHARGE vs AREAL DENSITY
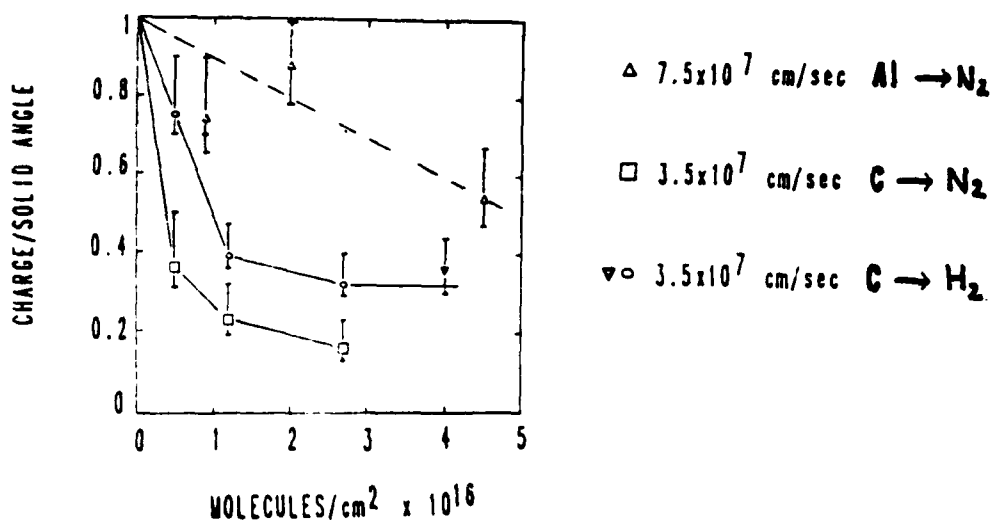
Figure 7   Debris ion charge per steradian (relative units) collected at various mass-pathlengths for several combinations of debris species and velocities and ambient gas parameters.   Significant loss of charge is seen above 10^{16} molecules/cm^2 at low velocity.

VISIBLE FRAMING PHOTOGRAPHS

SHOT 12531
139 J, 4.5 micron Al target
100 microns Nitrogen, B=800 Gauss
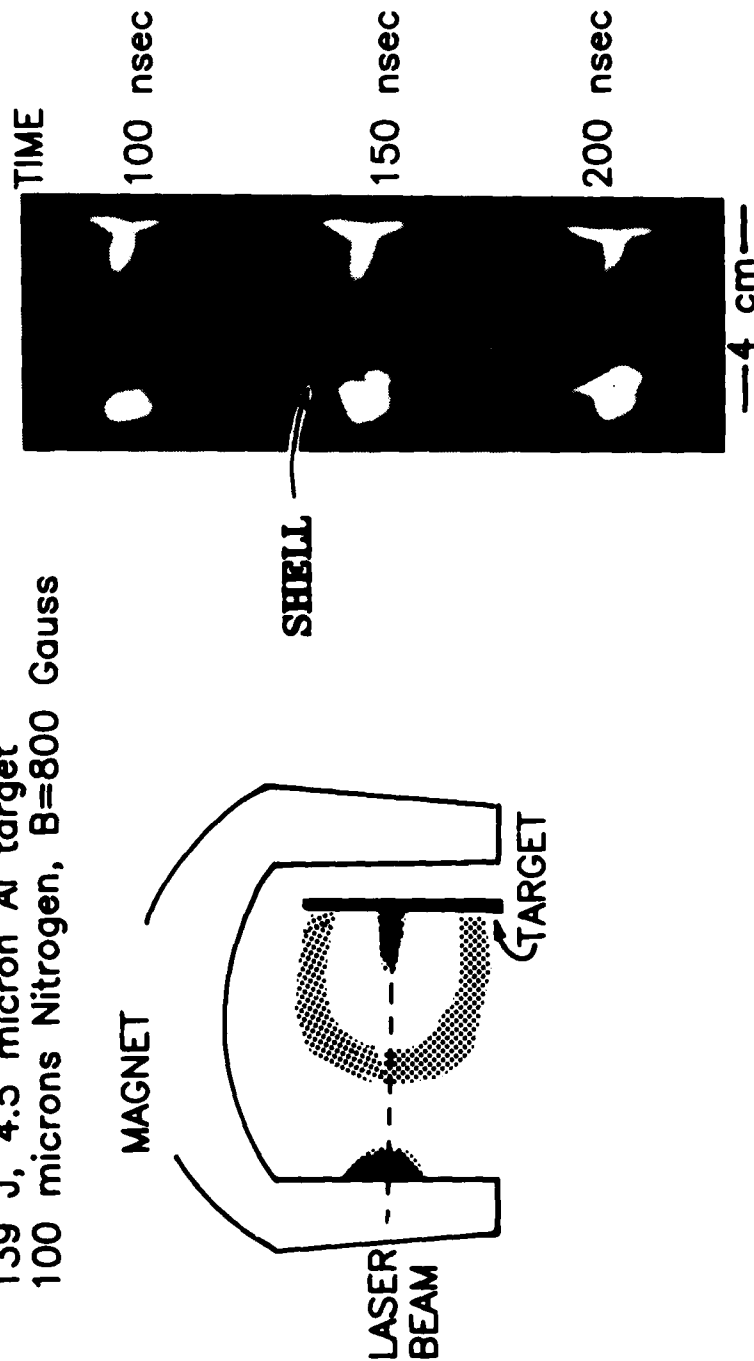
Figure 8   Framing photographs of the visible light emission from an expanding plasma shell.   Frame exposure times are 5 nsec.   Initial debris speed was about 6.6×10^7 cm/sec; shell speed is 2.5×10^7 cm/sec.
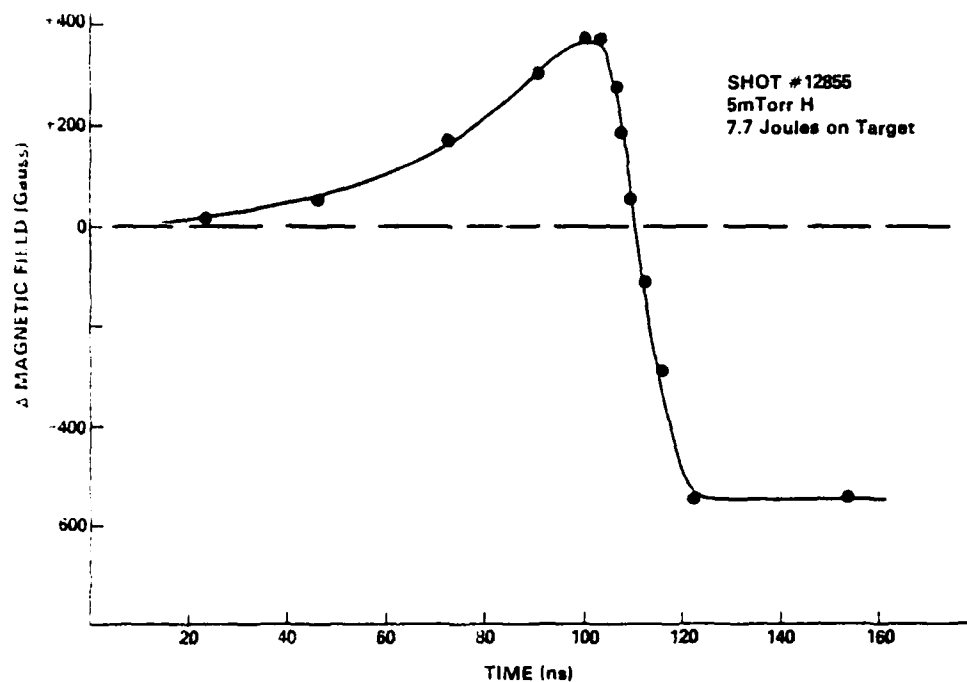
Figure 9   Temporal behavior of the change in magnetic field detected by a magnetic loop probe located 3 cm from the target. The applied field was 800 gauss. Note the field compression peak at 100 nsec and near depletion of the applied field (magnetic bubble) for t > 120 nsec.

19

TYPICAL INSTABILITY (M II)
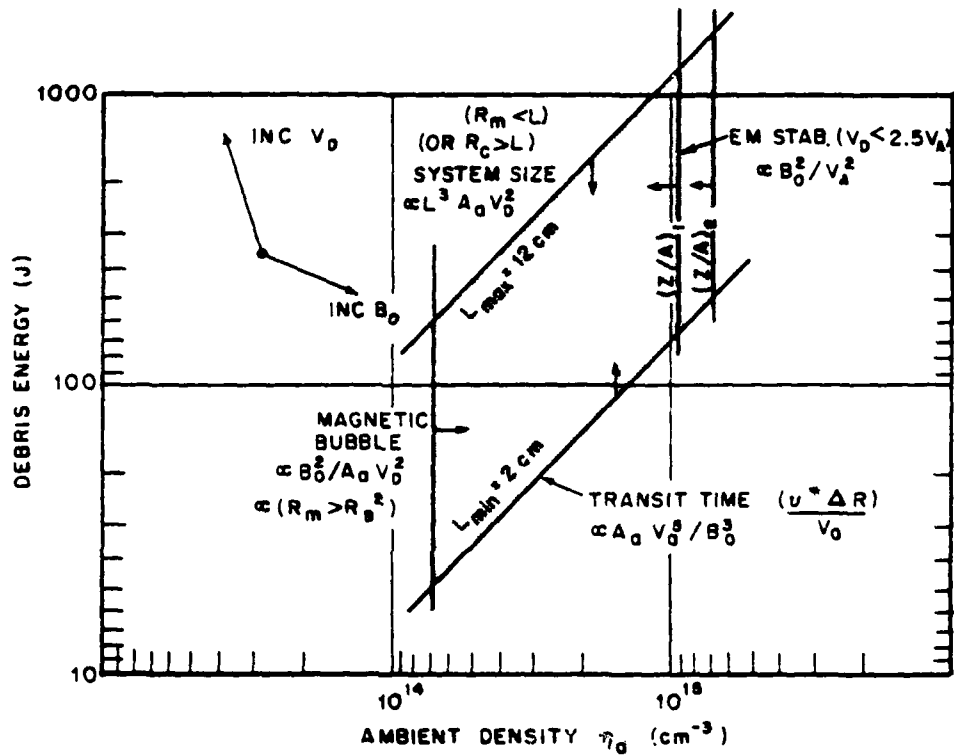
Figure 10   Magnetic ion-ion instability window (qualitative).   The unstable

region is bounded on the right by electromagnetic stabilization when

$V_D > 2.5 \ V_A$, on the left by the requirement that the energy density

in the debris plasma exceed that of the magnetic field, on the

bottom by requiring that the transit-time of an ambient ion passing

through the shell exceed one momentum transfer e-fold, and bounded

on the top by the practical requirement that the equal mass radius

fit inside the experiment.   The top can also be limited by the

cyclotron radius of the debris ions at high field strengths.

20
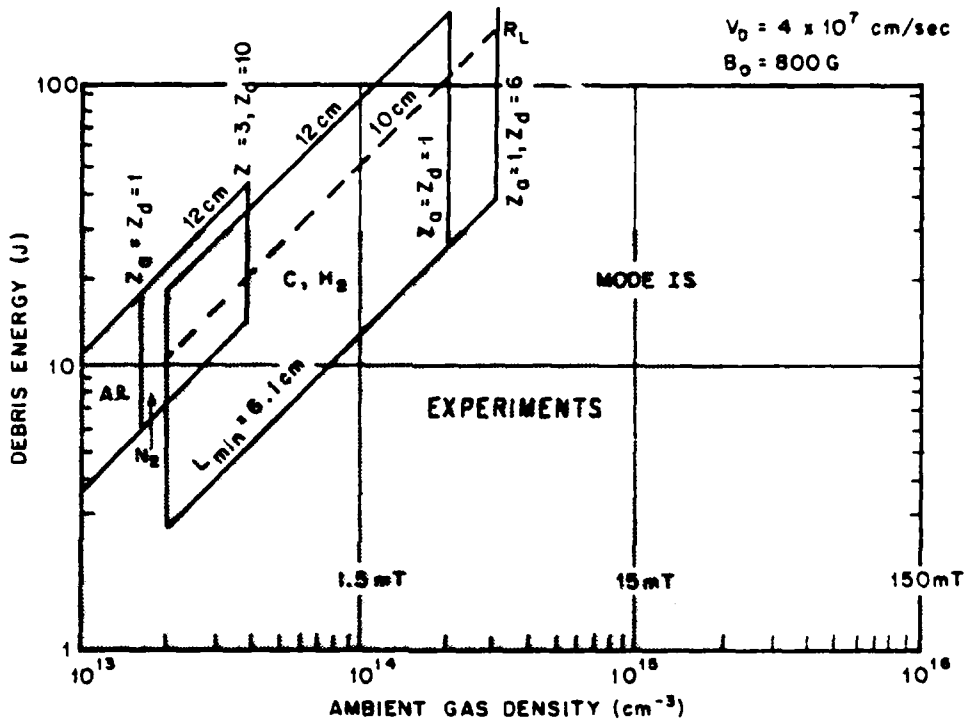
Figure 11 Parameter space for MII instability. The parallelograms are theoretical estimates of regions of instability and the circled area is the experimental region.
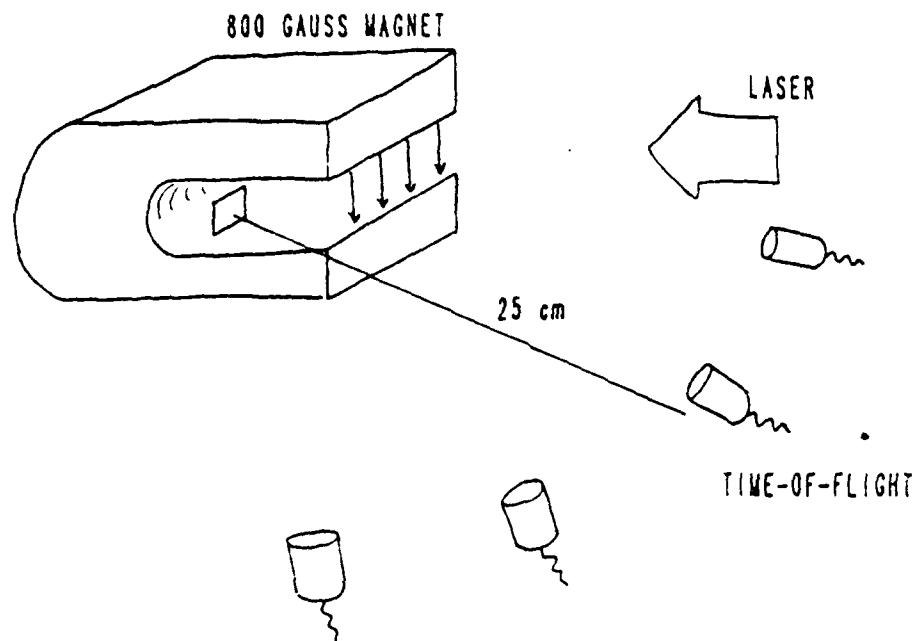
Figure 12   Arrangement to observe effects of magnetic field induced instability

from debris ion time-of-flight detectors.
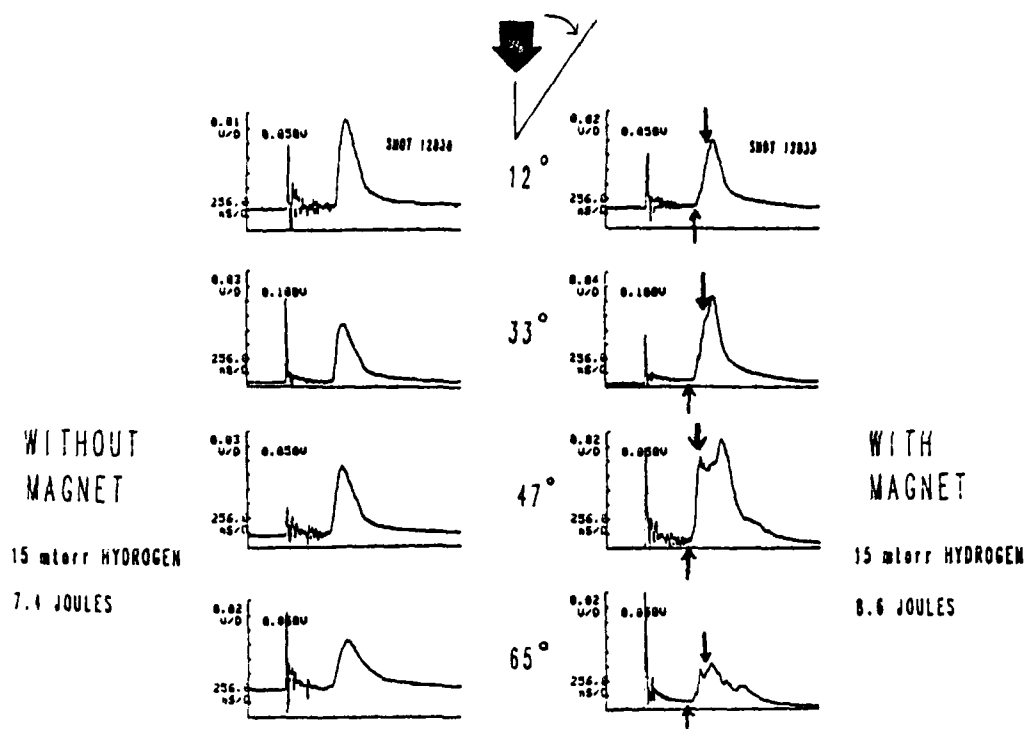
Figure 13   Comparision of debris ion time-of-flight traces without a magnetic
field present (left) and with a 800 G field present (right). Note
the distorted debris distributions in the presence of a magnetic
field.

WITH MAGNET

8 JOULES, 15 mtorr, 47° TO LASER AXIS
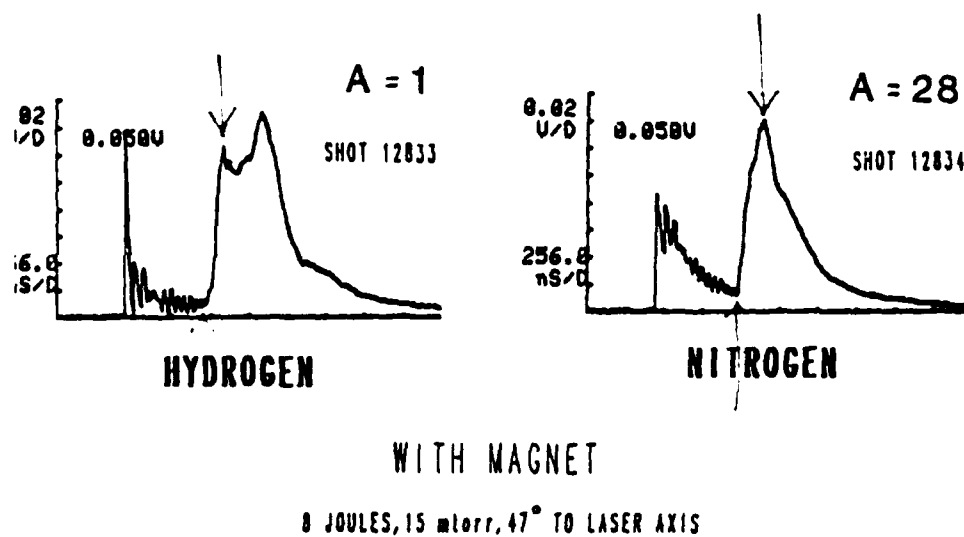
Figure 14. Comparison of debris ion distributions with atomic number of the
background gas.

23
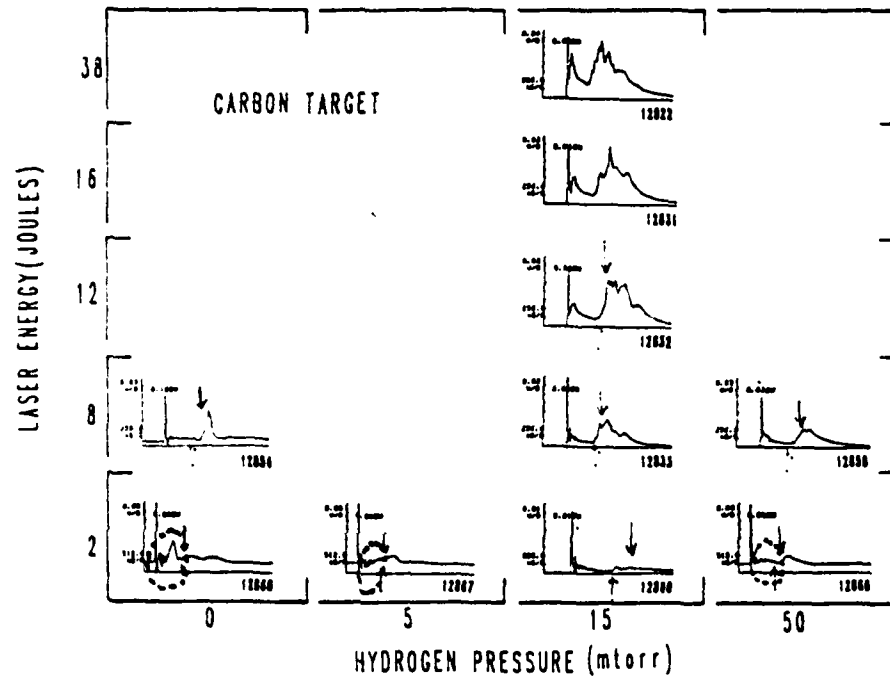
Figure 15. Debris ion time-of-flight signals often show "fast ions" at low laser energy in the presence of a magnetic field.

References

1. J.F. Vesecky et al., JASON Tech. Report #JSR-80-15 (1980). HANE Primer-DNA High Altitude Nuclear Effects Summer Study (to be publihsed 1984).

2. S.T. Kacenjar, B.H. Ripin, J.A. Stamper, J. Grun and E.A. McLean, NRL Memo Report #5260 (1984).

3. J.A. Stamper, B.H. Ripin, E.A. McLean, and S.P. Obenschain, NRL Memo Report #5278 (1984).

4. E.A. McLean, J.A. Stamper, H. Griem, W. Ali, B.H. Ripin, and C.K. Manka, NRL Memo Report #5274 (1984).

5. B.H. Ripin, J.A. Stamper, and E.A. McLean, NRL Memo Report 5279 (1984).

6. C. Prettie (to be published).

7. W. Chesnut, HANE Primer-DNA High Altitude Nuclear Effects Summer Study (to be published 1984).

8. J. Grun, M.H. Emery, M.J. Herbst, S. Kacenjar, C. Opal, E.A. McLean, S.P. Obenschain, and B.H. Ripin (to be published).

9. B.H. Ripin et al., NRL Memo Report #5078 (1983) and in "Laser Interaction and Related Plasma Phenomena," pg. 235-252, ed. H. Hora and G. Miley, Plenum Press (1983).

10. S.T. Kacenjar and C.K. Manka (to be published).

11. M.J. Herbst and J. Grun, Phys. Fluids 24, 1917 (1981); M.J. Herbst et al., NRL Memo Report #4893 (1980) and #5003 (1983); see also, "Laser Interaction and Related Plasma Phenomena," ed. H. Hora and G. Miley, Plenum Press (1983).

12. B.H. Ripin, DNA High-Altitude Nuclear Effects Summer Study (1982); see also HANE Working Group Meeting at NRL on Jan. 25-27 (1983).

13. R.R. Whitlock, M.H. Emery, J.A. Stamper, E.A. McLean, S.P. Obenschain and M.C. Peckerar, (to be published).

14. B.H. Ripin et al., in "Plasma Physics and Controlled Nuclear Fusion Research - 1982," p. 139-154, IAEA, Vienna, Austria (1983).

15. B.H. Ripin et al., Bull. Am. Phys. Soc. 25, 946 (1980).

16. J. Grun, M. Emery, M.J. Herbst, E.A. McLean, S.P. Obenschain, B.H. Ripin, J.A. Stamper, and R.R. Whitlock, NRL Memo Report #4896 (1983).

17. C. Longmire, M. Alme, R. Kilb, and C. Wright, MRC Report #AMRC-R-338 (1981).

18. M. Lampe, W.M. Manheimer, and K. Papadopoulos, NRL Memo Report #3076 (1975).

19. W. Tsai, L. DeRadd, Jr., and R. LeLevier, RDA Report #RDA-TR-125003-001 (1982).

20. R.A. Smith and J.D. Huba, NRL Memo Report #5092 (1983).

21. R. Stellingwerf, C. Longmire, and M. Alme, AMRC-465 (1983).

22. J.L. Sperling, JAYCOR Report #J530-83-102 (1983).

23. R. Decoste and B.H. Ripin, Phys. Rev. Lett. 40, 34 (1978).

24. B.H. Ripin et al., Phys. Fluids 23, 1012 (1980) and 24, 990 (1981).

25. J. Grun et al., Phys. Fluids 26, 588 (1983).

DISTRIBUTION LIST

NAVAL RESEARCH LABORATORY
WASHINGTON, DC 20375
   01CY ATTN CODE 4700 S.L. OSSAKOW
       26 CYS IF UNCLASS, 1 CY IF CLASS
   01CY ATTN CODE 4701 I. VITKOVITSKY
   01CY ATTN CODE 4780 J. Huba (10
       CYS IF UNCLASS, 1 CY IF CLASS)
   01CY ATTN CODE 7500
   01CY ATTN CODE 7550
   01CY ATTN CODE 7580
   01CY ATTN CODE 7551
   01CY ATTN CODE 7555
   01CY ATTN CODE 4730 E. MCLEAN
   01CY ATTN CODE 4108
   01CY ATTN CODE 4730 B. RIPIN
   20CY ATTN CODE 2628
  100CY ATTN CODE 4730

COMMANDER
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362
   01CY ATTN CAPT R. PITKIN

COMMANDER
NAVAL SPACE SURVEILLANCE SYSTEM
DHALGREN, VA 22448
   01CY ATTN CAPT J.H. BURTON

OFFICER-IN-CHARGE
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD 20910
   01CY ATTN CODE F31

DIRECTOR
STRATEGIC SYSTEMS PROJECT OFFICE
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20376
   01CY ATTN NSP-2141
   01CY ATTN NSSP-2722 FRED WIMBERLY

COMMANDER
NAVAL SURFACE WEAPONS CENTER
DAHLGREN LABORATORY
DAHLGREN, VA 22448
   01CY ATTN CODE DF-14 R. BUTLER

OFFICE OF NAVAL RESEARCH
ARLINGTON, VA 222L7
   01CY ATTN CODE 465
   01CY ATTN CODE 461
   01CY ATTN CODE 402
   01CY ATTN CODE 420
   01CY ATTN CODE 421

COMMANDER
AEROSPACE DEFENSE COMMAND/DC
DEPARTMENT OF THE AIR FORCE
ENT AFB, CO 90812
   01CY ATTN DC MR. LONG

COMMANDER AEROSPACE DEFENSE COMMAND/XPD
DEPARTMENT OF THE AIR FORCE
ENT AFB, CO 80912
   01CY ATTN XPDQQ
   01CY ATTN XP

AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA 01731
   01CY ATTN OPR HAROLD GARDNER
   01CY ATTN LKB KENNETH S.W. CHAMPION
   01CY ATTN OPR ALVA T. STAIR
   01CY ATTN PHD JURGEN BUCHAU
   01CY ATTN PHD JOHN P. MULLEN

AF WEAPONS LABORATORY
KIRTLAND AFB, NM 87117
   01CY ATTN SUL
   01CY ATTN CA ARTHUR H. GUENTHER
   01CY ATTN NTYCE LT. G. KRAJEI

AFTAC
PATRICK AFB, FL 32925
   01CY ATTN TF/MAJ WILEY
   01CY ATTN TN

AIR FORCE AVIONICS LABORATORY
WRIGHT-PATTERSON AFB, OH 45433
   01CY ATTN AAD WADE HUNT
   01CY ATTN AAD ALLEN JOHNSON

DEPUTY CHIEF OF STAFF
RESEARCH, DEVELOPMENT, & ACQ
DEPARTMENT OF THE AIR FORCE
WASHINGTON, DC 20030
   01CY ATTN AFRDQ

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION
DEPARTMENT OF THE AIR FORCE
HANSCOM AFB, MA 01731
   01CY ATTN J. DEAS

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION/YSEA
DEPARTMENT OF THE AIR FORCE
HANSCOM AFB, MA 01732
   01CY ATTN YSEA

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234
  01CY (ALL CORRES: ATTN SEC OFFICER FOR)

INSTITUTE FOR TELECOM SCIENCES
NATIONAL TELECOMMUNICATIONS & INFO ADMIN
BOULDER, CO 80303
  01CY ATTN A. JEAN (UNCLASS ONLY)
  01CY ATTN W. UTLAUT
  01CY ATTN D. CROMBIE
  01CY ATTN L. BERRY

NATIONAL OCEANIC & ATMOSPHERIC ADMIN
ENVIRONMENTAL RESEARCH LABORATORIES
DEPARTMENT OF COMMERCE
BOULDER, CO 80302
  01CY ATTN R. GRUBB
  01CY ATTN AERONOMY LAB G. REID

DEPARTMENT OF DEFENSE CONTRACTORS

AEROSPACE CORPORATION
P.O. BOX 92957
LOS ANGELES, CA 90009
  01CY ATTN I. GARFUNKEL
  01CY ATTN T. SALMI
  01CY ATTN V. JOSEPHSON
  01CY ATTN S. BOWER
  01CY ATTN D. OLSEN

ANALYTICAL SYSTEMS ENGINEERING CORP
5 OLD CONCORD ROAD
BURLINGTON, MA 01803
  01CY ATTN RADIO SCIENCES

AUSTIN RESEARCH ASSOC., INC.
1901 RUTLAND DRIVE
AUSTIN, TX 78758
  01CY ATTN L. SLOAN
  01CY ATTN R. THOMPSON

BERKELEY RESEARCH ASSOCIATES, INC.
P.O. BOX 983
BERKELEY, CA 94701
  01CY ATTN J. WORKMAN
  01CY ATTN C. PRETTIE
  01CY ATTN S. BRECHT

BOEING COMPANY, THE
P.O. BOX 3707
SEATTLE, WA 98124
  01CY ATTN G. KEISTER
  01CY ATTN D. MURRAY
  01CY ATTN G. HALL
  01CY ATTN J. KENNEY

CHARLES STARK DRAPER LABORATORY, INC.
555 TECHNOLOGY SQUARE
CAMBRIDGE, MA 02139
  01CY ATTN D.B. COX
  01CY ATTN J.P. GILMORE

COMSAT LABORATORIES
LINTHICUM ROAD
CLARKSBURG, MD 20734
  01CY ATTN G. HYDE

CORNELL UNIVERSITY
DEPARTMENT OF ELECTRICAL ENGINEERING
ITHACA, NY 14850
  01CY ATTN D.T. FARLEY, JR.

ELECTROSPACE SYSTEMS, INC.
BOX 1359
RICHARDSON, TX 75080
  01CY ATTN H. LOGSTON
  01CY ATTN SECURITY (PAUL PHILLIPS)

EOS TECHNOLOGIES, INC.
606 Wilshire Blvd.
Santa Monica, Calif 90401
  01CY ATTN C.B. GABBARD

ESL, INC.
495 JAVA DRIVE
SUNNYVALE, CA 94086
  01CY ATTN J. ROBERTS
  01CY ATTN JAMES MARSHALL

GENERAL ELECTRIC COMPANY
SPACE DIVISION
VALLEY FORGE SPACE CENTER
GODDARD BLVD KING OF PRUSSIA
P.O. BOX 8555
PHILADELPHIA, PA 19101
  01CY ATTN M.H. BORTNER SPACE SCI LAB

GENERAL ELECTRIC COMPANY
P.O. BOX 1122
SYRACUSE, NY 13201
  01CY ATTN F. REIBERT

GENERAL ELECTRIC TECH SERVICES CO., INC.
HMES
COURT STREET
SYRACUSE, NY 13201
  01CY ATTN G. MILLMAN

GEOPHYSICAL INSTITUTE
UNIVERSITY OF ALASKA
FAIRBANKS, AK 99701
  (ALL CLASS ATTN: SECURITY OFFICER)
  01CY ATTN T.N. DAVIS (UNCLASS ONLY)
  01CY ATTN TECHNICAL LIBRARY
  01CY ATTN NEAL BROWN (UNCLASS ONLY)

GTE SYLVANIA, INC.
ELECTRONICS SYSTEMS GRP-EASTERN DIV
77 A STREET
NEEDHAM, MA 02194
  01CY ATTN DICK STEINHOF

HSS, INC.
2 ALFRED CIRCLE
BEDFORD, MA 01730
  01CY ATTN DONALD HANSEN

ILLINOIS, UNIVERSITY OF
107 COBLE HALL
150 DAVENPORT HOUSE
CHAMPAIGN, IL 61820
  (ALL CORRES ATTN DAN MCCLELLAND)
  01CY ATTN K. YEH

INSTITUTE FOR DEFENSE ANALYSES
1801 NO. BEAUREGARD STREET
ALEXANDRIA, VA 22311
  01CY ATTN J.M. AEIN
  01CY ATTN ERNEST BAUER
  01CY ATTN HANS WOLFARD
  01CY ATTN JOEL BENGSTON

INTL TEL & TELEGRAPH CORPORATION
500 WASHINGTON AVENUE
NUTLEY, NJ 07110
  01CY ATTN TECHNICAL LIBRARY

JAYCOR
11011 TORREYANA ROAD
P.O. BOX 85154
SAN DIEGO, CA 92138
  01CY ATTN J.L. SPERLING

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
  01CY ATTN DOCUMENT LIBRARIAN
  01CY ATTN THOMAS POTEMRA
  01CY ATTN JOHN DASSOULAS

KAMAN SCIENCES CORP
P.O. BOX 7463
COLORADO SPRINGS, CO 80933
  01CY ATTN T. MEAGHER

KAMAN TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET (P.O DRAWER QQ)
SANTA BARBARA, CA 93102
  01CY ATTN DASIAC
  01CY ATTN WARREN S. KNAPP
  01CY ATTN WILLIAM MCNAMARA
  01CY ATTN B. GAMBILL

LINKABIT CORP
10453 ROSELLE
SAN DIEGO, CA 92121
  01CY ATTN IRWIN JACOBS

LOCKHEED MISSILES & SPACE CO., INC
P.O. BOX 504
SUNNYVALE, CA 94088
  01CY ATTN DEPT 60-12
  01CY ATTN D.R. CHURCHILL

LOCKHEED MISSILES & SPACE CO., INC.
3251 HANOVER STREET
PALO ALTO, CA 94304
  01CY ATTN MARTIN WALT DEPT 52-12
  01CY ATTN W.L. IMHOF DEPT 52-12
  01CY ATTN RICHARD G. JOHNSON DEPT 52-12
  01CY ATTN J.B. CLADIS DEPT 52-12

MARTIN MARIETTA CORP
ORLANDO DIVISION
P.O. BOX 5837
ORLANDO, FL 32805
  01CY ATTN R. HEFFNER

M.I.T. LINCOLN LABORATORY
P.O. BOX 73
LEXINGTON, MA 02173
  01CY ATTN DAVID M. TOWLE
  01CY ATTN L. LOUGHLIN
  01CY ATTN D. CLARK

34

MCDONNEL DOUGLAS CORPORATION
5301 BOLSA AVENUE
HUNTINGTON BEACH, CA 92647
  01CY ATTN N. HARRIS
  01CY ATTN J. MOULE
  01CY ATTN GEORGE MROZ
  01CY ATTN W. OLSON
  01CY ATTN R.W. HALPRIN
  01CY ATTN TECHNICAL LIBRARY SERVICES

MISSION RESEARCH CORPORATION
735 STATE STREET
SANTA BARBARA, CA 93101
  01CY ATTN P. FISCHER
  01CY ATTN W.F. CREVIER
  01CY ATTN STEVEN L. GUTSCHE
  01CY ATTN R. BOGUSCH
  01CY ATTN R. HENDRICK
  01CY ATTN RALPH KILB
  01CY ATTN DAVE SOWLE
  01CY ATTN F. FAJEN
  01CY ATTN M. SCHEIBE
  01CY ATTN CONRAD L. LONGMIRE
  01CY ATTN B. WHITE

MISSION RESEARCH CORP.
1720 RANDOLPH ROAD, S.E.
ALBUQUERQUE, NEW MEXICO 87106
  01CY R. STELLINGWERF
  01CY M. ALME
  01CY L. WRIGHT

MITRE CORPORATION, THE
P.O. BOX 208
BEDFORD, MA 01730
  01CY ATTN JOHN MORGANSTERN
  01CY ATTN G. HARDING
  01CY ATTN C.E. CALLAHAN

MITRE CORP
WESTGATE RESEARCH PARK
1820 DOLLY MADISON BLVD
MCLEAN, VA 22101
  01CY ATTN W. HALL
  01CY ATTN W. FOSTER

PACIFIC-SIERRA RESEARCH CORP
12340 SANTA MONICA BLVD.
LOS ANGELES, CA 90025
  01CY ATTN E.C. FIELD, JR.

PENNSYLVANIA STATE UNIVERSITY
IONOSPHERE RESEARCH LAB
318 ELECTRICAL ENGINEERING EAST
UNIVERSITY PARK, PA 16802
  (NO CLASS TO THIS ADDRESS)
  01CY ATTN IONOSPHERIC RESEARCH LAB

PHOTOMETRICS, INC.
4 ARROW DRIVE
WOBURN, MA 01801
  01CY ATTN IRVING L. KOFSKY

PHYSICAL DYNAMICS, INC.
P.O. BOX 3027
BELLEVUE, WA 98009
  01CY ATTN E.J. FREMOUW

PHYSICAL DYNAMICS, INC.
P.O. BOX 10367
OAKLAND, CA 94610
  ATTN A. THOMSON

R & D ASSOCIATES
P.O. BOX 9695
MARINA DEL REY, CA 90291
  01CY ATTN FORREST GILMORE
  01CY ATTN WILLIAM B. WRIGHT, JR.
  01CY ATTN ROBERT F. LELEVIER
  01CY ATTN WILLIAM J. KARZAS
  01CY ATTN H. ORY
  01CY ATTN C. MACDONALD
  01CY ATTN R. TURCO
  01CY ATTN L. DeRAND
  01CY ATTN W. TSAI

RAND CORPORATION, THE
1700 MAIN STREET
SANTA MONICA, CA 90406
  01CY ATTN CULLEN CRAIN
  01CY ATTN ED BEDROZIAN

RAYTHEON CO.
528 BOSTON POST ROAD
SUDBURY, MA 01776
  01CY ATTN BARBARA ADAMS

RIVERSIDE RESEARCH INSTITUTE
330 WEST 42nd STREET
NEW YORK, NY 10036
  01CY ATTN VINCE TRAPANI

SCIENCE APPLICATIONS, INC.
1150 PROSPECT PLAZA
LA JOLLA, CA 92037
  01CY ATTN LEWIS M. LINSON
  01CY ATTN DANIEL A. HAMLIN
  01CY ATTN E. FRIEMAN
  01CY ATTN E.A. STRAKER
  01CY ATTN CURTIS A. SMITH
  01CY ATTN JACK MCDOUGALL

SCIENCE APPLICATIONS, INC
1710 GOODRIDGE DR.
MCLEAN, VA 22102
  ATTN: J. COCKAYNE

SRI INTERNATIONAL
333 RAVENSWOOD AVENUE
MENLO PARK, CA 94025
  01CY ATTN DONALD NEILSON
  01CY ATTN ALAN BURNS
  01CY ATTN G. SMITH
  01CY ATTN R. TSUNODA
  01CY ATTN DAVID A. JOHNSON
  01CY ATTN WALTER G. CHESNUT
  01CY ATTN CHARLES L. RINO
  01CY ATTN WALTER JAYE
  01CY ATTN J. VICKREY
  01CY ATTN RAY L. LEADABRAND
  01CY ATTN G. CARPENTER
  01CY ATTN G. PRICE
  01CY ATTN R. LIVINGSTON
  01CY ATTN V. GONZALES
  01CY ATTN D. MCDANIEL

TECHNOLOGY INTERNATIONAL CORP
75 WIGGINS AVENUE
BEDFORD, MA 01730
  01CY ATTN W.P. BOQUIST

TOYON RESEARCH CO.
P.O. Box 6890
SANTA BARBARA, CA 93111
  01CY ATTN JOHN ISE, JR.
  01CY ATTN JOEL GARBARINO

TRW DEFENSE & SPACE SYS GROUP
ONE SPACE PARK
REDONDO BEACH, CA 90278
  01CY ATTN R. K. PLEBUCH
  01CY ATTN S. ALTSCHULER
  01CY ATTN D. DEE
  01CY ATTN D/ STOCKWELL
           SNTF/1575

VISIDYNE
SOUTH BEDFORD STREET
BURLINGTON, MASS 01803
  01CY ATTN W. REIDY
  01CY ATTN J. CARPENTER
  01CY ATTN C. HUMPHREY